Interpretation of Optical Surface in the Midst of Polishing

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Shōtarō YOSHIDA

The Research Institute for Scientific Measurements

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I. Introduction

For the finishing of precise optical surfaces, pitch or wax tools and rouge are used commonly. In these processes the figures of surfaces really formed are influenced by the arm length of the polishing machine, amplitude of movement, polishing pressure, suitability of rouging, uniformity of netting on the tool surface, elastic deformation and partial inhomogenuity of the tool, irregularity of the quality of the tool itself, change of temperature during the polishing, and other miscellaneous complex factors.

Influences of mechanical conditions of polishing machine upon the optical surface were studied theoretically by Dévé(1), and a few qualitative results were reported for other factors(2), but no clear relations were known up to the present for the most part of these causes.

In fact, it is almost impossible to predict the final figure of finished surface by the above knowledge, and the finishing of high precision optical surfaces are at present mainly committed to the personal experiences of an individual operator.

I made also many experiments on this subject, and found the important fact that the effect of polishing is by no means proportional to the driving time of the polishing machine. No effective polishing is performed before the perfect coincidence of the tool and work, which takes some hours after the machines were started.

All theories and rules hitherto proposed were constituted on the assumption that the abrasive is distributed thinly and uniformly over the whole polishing surface, but in reality, this assumption itself holds not so easily.

II. The Four conditions of Effective Polishing

Either by an interference test of the polished optical surface, or by an observation of the discolouration of the tool, it is easy to decide whether the polishing was effective or not. But it is useless as this process destroys the effective condition at all. Then, by what method can we interpret this effective state, without stopping the motion of a machine?

I have polished many circular glass plates with beeswax tool and rouge, diameters of plates being from 2 to 7 cm. I found in an effective polishing that the following four conditions always hold without fail, namely:

1. Rouge is distributed thinly and uniformly over the whole surface of the wax tool. This is the condition usually called "rouge spreads".
2. Clockwise and counter-clockwise resistances are equal when one rotates the work by one's hand.
3. Strength of resistances are definite according to the contact area and density of the rouge.
4. Rotation velocity of the work reaches to some definite value, and its sense is always direct.

In my experiments, beeswax tools are attached to the lower axis of the machine, which rotates counter-clockwise by constant speed. Works are placed on the tool, and rotate freely. "Direct" means that the tool and work rotate in the same direction, and "Retrograde" means that they rotate opposite to each other.

As these conditions are the reliable symptoms of effective polishing, I will call them hereafter "the four conditions of effective polishing".

The first condition will need no explanation. In this case rouge never gets out from the edge of the work.

Resistance of the work in the second and third conditions is difficult to measure accurately, but their values are between 200 and 500 grams-weight for ordinary cases, such as single polishing of prisms and mirrors having moderate sizes. The wider the contact area, the larger the resistance, but no linear relations were observed.

The definite rotation velocity in the fourth condition depends upon various factors, such as the revolution number of the machine, the density of rouge used, the contact area between tool and work, etc. For example, these velocities are between 10 and 40 revolutions per minute, when the tool rotates from 23 to 30 revolutions per minute. It cannot be sure that the work rotates slower than the tool.

When the four conditions above described have been fulfiled, the whole surface of the work coincides perfectly with the tool, and effective polishing is perfomed in all parts. In other words, if these conditions were perfectly satisfied by polishing with truly flat beeswax tool, and then stop the machine immediately and test the glass surface, you will surely find the true flat. In my experience of this method, no special skills were required to make an optical flat within the accuracy of one quarter of a wave length.

However, these circumstances will not hold at all when the adherence of beeswax to the base-plate is uncertain. Sudden cooling or heating of the tool must be avoided, and the tool grooving should not be too deep.

III. Observed Phenomena When The Works and Tools are Not Perfectly Coincident

In the previous paragraph I showed the phenomena found when the works and tools are perfectly coincident. In other cases, the following facts were observed.

The surface of the work is always convex relative to that of the tool when the work rotates too slowly. This is also the case where the resistance is too light when the work has turned by hand. The lighter the resistance, the more convex relatively one another. They show slight mutual friction as the contact area is limited to small portion near the centre.

This estimation is surprisingly accurate. No special skills are needed for me to predict the convexity of a polished surface up to half a wave length, only by the feeling from my hand, without testing it by the interference fringes.

The relative convexity between the tool and work is more stronger, when the work retrogrades. In most cases the difference among them are 5 fringes or more. In some cases, the work reaches to the stationary direct rotation after the retrograde rotation for a few seconds. This is harmless, for it is due to the moisture of rouge.

In case of more stronger convexity, the work stops entirely at first. A little later, when rouge spreads on some part, rapid retrogression will take place suddenly.

It is a reliable omen of mutual concavity that rouge does not spread uniformly, in spite of the fact that resistances of the work on both sides are heavy. In this case also, the heavier the resistance, the more concave is the surface mutually. Concavity of one interference fringe will be predicted without difficulty.

Many occasions are frequently left unnoticed when the first and third conditions are fulfiled, notwithstanding the second and fourth being not satisfied. Namely, rouge distributes uniformly all over the surface, and resistances are comparatively well, but the lefthand resistance is somewhat unequal to that of the righthand, or the rotation velocity of the work is inadequate. In general, these phenomena show the over-polishing. That is, polishing too long after the four conditions have already been fulfiled. Test the glass surface at this time, you will surely find the central portion being depressed, the outer zone somewhat elevated, and the edge turned down again, like the reversed Schmidt correcting plate.

IV. Remarks

It must always be remembered that almost no polishing effect is observed before the spreading of rouge, but, once the perfect coincidence has happened, polishing becomes suddenly effective.

The time before an occurrence of an effective polishing is influenced by many factors, such as the mechanical conditions of the machine, the contact area, density of rouge, quality of the tool, temperature, as well as the curvature difference between tool and work. In general, it is between 5 and 30 minutes. Moreover, at the most the time is from 30 seconds to a minute, when these four conditions perfectly hold. And, if this chance is lost, the surface will become over-polishing. It is essential to catch the moment when convex turns into concave.

The facts above described are important symptoms for the interpretation of optical surfaces without interrupting the polishing action. Accurate optical flats can be polished speedily by applying this principle. The cracks on the finished surface or the ware of mother flats can also be avoided effectively. To finish the optical flats we lost very much time up to the present, because we had no means of knowing the over-polishing.

It is most effective to test the surface at the moment when they satisfy the four conditions. Excessively frequent tests are almost useless. To improve the efficiency, we must reduce the repetition of testing as little as we can.

Only a few preliminary results are reported in this paper. Applying the above principle, it will be possible to stop the polishing automatically when the surface becomes flat, the devices of which I am now disigning.

Details on the treatments of a beeswax tool, and other practical remarks on the polishing of optical surfaces, will be found in my book[3].

Summary

The polishing action is not proportional to the driving time of the machine. From many experiments using beeswax tools, I found the four conditions of effective polishing. Figure of an optical surface can be estimated without stopping the polishing machine. Considerably accurate optical flats can be finished within a short time.

References

(1) Dévé, C. C.: Le Travail des Verres d' Optique de Précision, (1936).

(2) Strong, J,: Procedures in Experimental Physics, (1942).

(3) Yoshida, S.: Polishing Technique of Optical Parts. (in Japanese, 1950)